ATOMIC PHYSICS

Atomic beam lasers

To increase frequency stability some researchers take advantage of the orderliness of moving beams of atoms

by Dietrick E. Thomsen

In the few years they have been around, lasers have become almost proverbial for their hair-fine exactness. Noted for their intense beams of monochromatic light, they can cut metal or weld detached retinas with equal finesse.

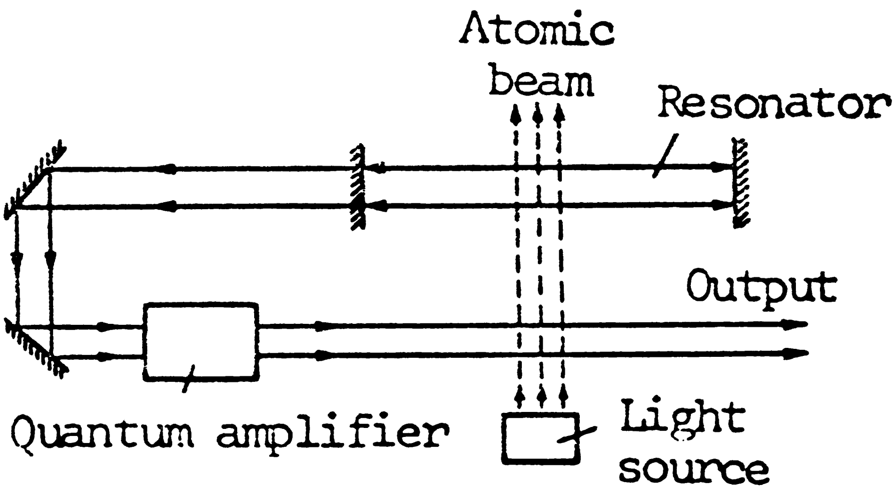
But for people working on the narrowest edge of science and technology, lasers are still not sharp enough. Those researchers are demanding tolerances beyond the state of the art; they want a frequency that doesn't vary more than one part in a thousand billion, or ten times that if they can get it. And they want this stability to last for years.

On that knife-edge of research rest such basics as relativity theory and the question of the constancy of the speed of light, which is vital to relativity. There is, for example, a level of laser precision which would permit physicists to test again, to a new level of tolerance, the Michelson-Morley experiment—the one that led to the special relativity theory. This experiment aims to prove that there is no difference in the speed of light whether it is measured in the direction of the earth's motion or across it. On this result hang all the principles of special relativity—since special relativity is based on the notion that the speed of light is the same whether one moves with it or across it.

The experiment was first done—with mirrors—by Albert A. Michelson and Edward W. Morley in 1887. But when a principle depends on an experimental result being exactly zero physicists are always a little nervous. They want to keep checking as measurement accuracy improves. So far the results of all repetitions have been confirmation, but there is no certainty—even if there is a strong expectation—that use of ultra-sharp lasers will confirm this.

Lasers of greater stability could also be used for extremely accurate measurements of long distances. The high stability would be especially helpful where very fine distinctions are sought.

For example, some theories of cosmology postulate that the mass of any body is not constant but depends at any moment on the distribution in space of the remainder of the mass in the universe. If this were true, and if the masses in the neighborhood of the earth were unevenly distributed, then a body moving in one direction with respect to the milky way should show an amount of mass different from what it shows when it moves in another direction. Such an effect, to have escaped detection by astronomers over the centuries, would have to be ultraminiscule; extraordinarily accurate tracking of celestial bodies, using extraordinarily precise lasers over a long time, might show it.



JETP Letters

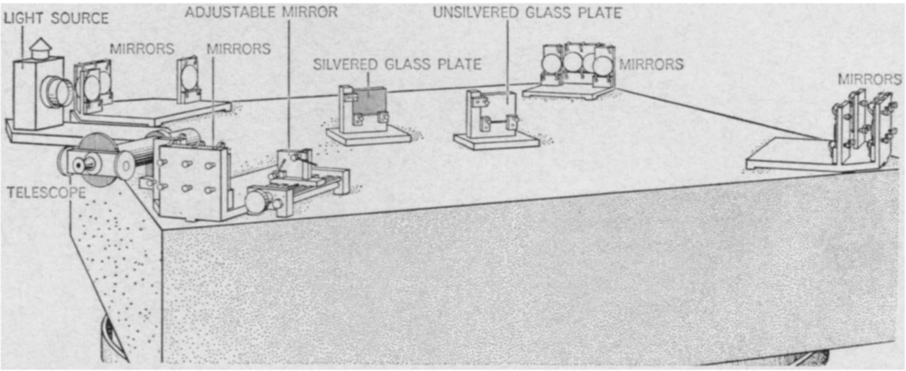
Basov's idea of how an atomic beam laser might be put together.

Another form of tiny slow motion is that involved in long term changes in the shape of the earth. Laser seismometers could record these changes provided they could maintain high stability for years.

Such experiments are "why I am in it," says Dr. Rainer Weiss of the Massachusetts Institute of Technology, currently involved in efforts to make long-term, highly stable lasers.

The frequency spreads and drifts of ordinary lasers are caused principally by the chaotic motion of atoms in the laser's reasonant cavity. One approach to more stability—so new that the development-hungry laser industry has not yet snatched it from the university laboratories—is to use as a tuner the orderly motions in atomic beams, streams of atoms moving in a more or less organized way instead of in the random fashion of atoms in the gases or solids lasers usually employ.

An ordinary laser depends on the fluorescent properties of gases or solids.



Scientific American

Michelson-Morley experiment compares light speed in two directions.

. . . atomic beams

If a collection of atoms is energetically pumped—that is, energy is put in from an outside source such as a light or a spark discharge—the atoms will be excited to a higher energy state. In time they will radiate the excess energy by emitting light in frequencies characteristic of the atoms.

But even single-frequency light, as is the case with neon lights, is random in phase and goes in all directions.

To give it coherence—to make all the emitting atoms work together—one puts the emitter in a box with mirrors at the ends. The distance between the mirrors is made equal to a precise number of wavelengths. This causes formation of a standing wave—one that vibrates up and down like a guitar string, without going anywhere.

The standing wave condition forces all the emitting atoms to work in phase—all their motions go to amplify the wave until a great deal of energy is concentrated in it. The amplified wave leaks energy from the tube through a partially transparent mirror.

So it is in principle. But in practice there are roughnesses. The emissions of the atoms are not at a single, precise frequency, but in a slight, yet measurable band of frequencies. This is a result of the structure of the atoms, and not much can be done about it.

Working on the narrowest edge of science and technology.

Superimposed on this, however, is a wider spread, the Doppler bandwidth. This arises because any atom that happens to be moving emits radiation at a slightly shifted wavelength from the one it has when it is still. A collection of millions of such random variations causes a smearing of the line.

In addition, in a gas laser there are also collisions which distort the atoms and cause the emission to slide off frequency.

In an atomic beam, however, one can control the Doppler width by making the motion of the stream highly uniform. There are also no collisions. Here lies the secret of the high, long-term stability.

One way to take advantage of the properties of the atomic beam is to use it as the laser emitter, running it through the box or resonator cavity. An effort of this sort is going on at Yale University, according to Prof. W. R. Bennett Jr., but the work is still in a very early stage. The experimenters are trying to develop a system in which a beam of neutral atoms lases after being excited by a beam of electrons.

Yale

Bennett: Will it oscillate?

MIT

Weiss: Checking the constancy of c.

The same idea has been mentioned in Russian scientific literature, first by Academician N. G. Basov and by Drs. V. S. Letokhov and B. D. Pavlik of the P. N. Lebedev Institute in Moscow.

Development of such a laser involves overcoming low power difficulties arising from the low density of the beams. The Yale researchers are still waiting "to see whether it will oscillate," says Dr. Bennett.

Another approach would use the atomic beam to control the tuning of an ordinary laser. To do this one has to find a substance which emits energy at a frequency that matches that of the laser one wants to use.

For example, at MIT, Shaoul Ezekiel

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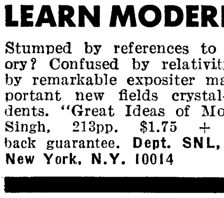

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. . . lasers

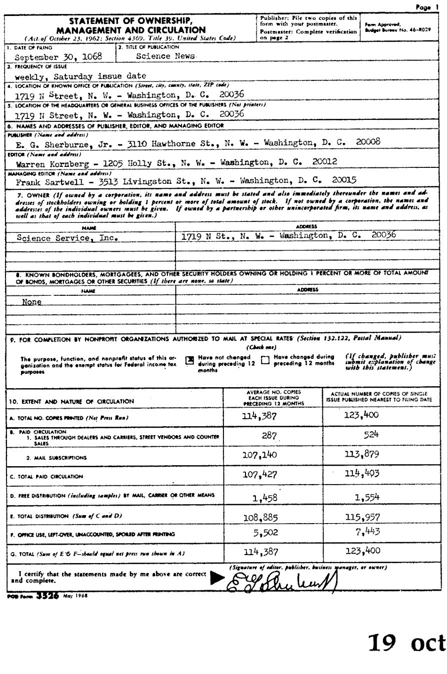
and Dr. Weiss use a molecular beam of iodine, which fluoresces on irradiation by 5145-angstrom light from an argon laser. The laser excites the iodine atoms at their precise frequency and the resultant energy emission is then fed back to the laser to make its emission more precise.

This kind of tuning can also be done by using the beam to absorb, rather than emit energy, taking advantage of what might be called a reversed Lamb dip.

The standard Lamb dip results from another imprecision in practical lasers: In principle a standing wave in a resonator is the sum of two running waves that are going in opposite directions and coincide exactly with each other. But in an actual laser the two running waves are usually slightly out of coincidence. In this state they each take energy from a different set of atoms. But when the laser is tuned to the middle of its bandwidth, the two waves come into coincidence. Then they feed off the same population, there is suddenly less energy and the brightness of the emission drops off as much as 50 percent.

This so-called Lamb dip serves as a very good indicator of a reference wavelength, especially if one reverses the process, and uses an atomic beam as an absorber of laser light. In this case, it is the absorption that falls off at the Lamb dip frequency, and a sharp peak appears in the transmitted light. This peak signal can then be fed back to tune the laser.

Such an approach is being used in the Soviet Union, especially by Academician Basov. "The last time I saw him," says Prof. Bennett, "he told me he was using formaldehyde."



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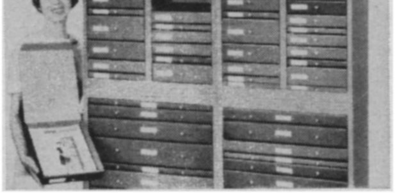

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